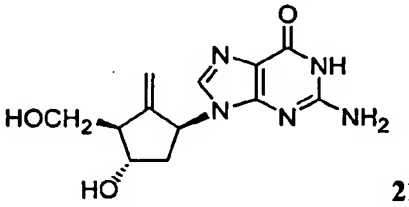
CLAIMS

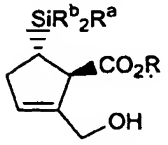
The invention claimed is:

1. A process for the preparation of entecavir having the formula



21, comprising:

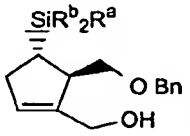
(a) treating an ester of the formula



66,

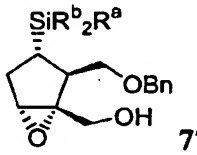
wherein R^a is allyl, phenyl, C_1 to C_6 alkylphenyl, or C_1 to C_6 alkoxyphenyl; R^b is C_1 to C_6 alkyl; and R is C_1 to C_4 alkyl or benzyl;

with an enol ether of acetone and an acid to protect the hydroxy group, followed by treatment with a hydride reagent to reduce the carboxylic acid ester moiety, and then alkylating the resulting alcohol with a benzyl halide and removing the enol ether hydroxy protecting group to give an allylic alcohol of the formula



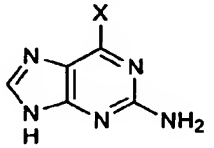
76;

(b) epoxidizing the product from step (a) with a diastereoselective epoxidation to give a cyclopentane epoxide having the formula



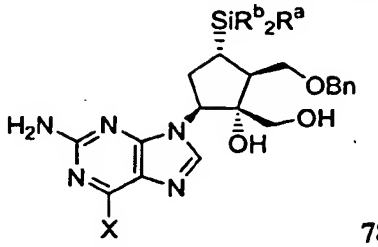
77;

(c) treating the cyclopentane epoxide from step (b) with an alkali metal salt of a purine compound of formula



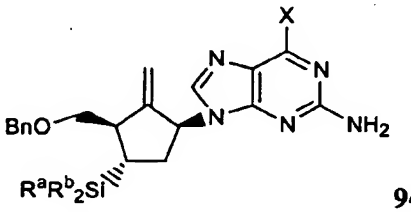
28,

wherein X is Cl, I, or benzyloxy, to give a compound of formula



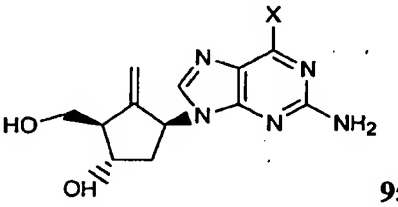
78;

(d) when X is Cl or I, converting the vicinal diol of formula **78** to the methylene compound of formula,



94;

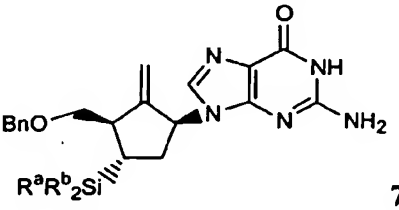
(e) hydrolyzing the benzyl ether moiety on the primary alcohol of compound **94** and converting the silane moiety of compound **95** to a hydroxy moiety to give a compound of formula,



95; and

(f) hydrolyzing the chloro or iodo moiety X to provide the compound of formula **21**; or

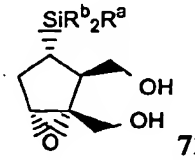
(d') when X is benzyloxy, converting the vicinal diol of formula **78** to the methylene compound of formula



79; and

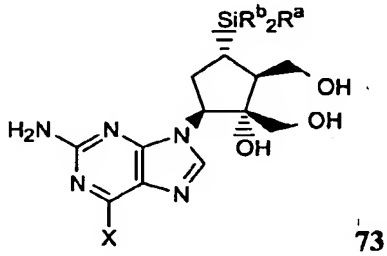
(e') hydrolyzing the benzyl ether moiety on the primary alcohol of compound **79** and converting the silane moiety to a hydroxy moiety to provide the compound of formula **21**; or

(a") epoxidizing the ester of formula **66** with a diastereo selective expoxidation, to give a cyclopentane epoxide having the formul



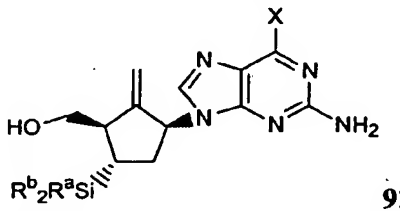
72;

(b") treating the cyclopentane epoxide from step (a") with an alkali metal salt of the purine compound of formula **28** to give a compound of formula



73;

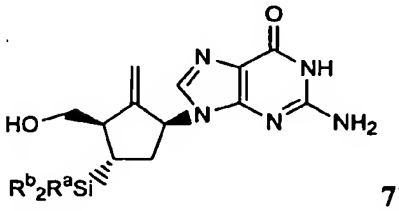
(c") when X is Cl or I, converting the vicinal diol of formula **73** to the methylene compound of formula



92; and

(d") converting the silane moiety of compound **92** to a hydroxy moiety and hydrolyzing the chloro or iodo moiety X to provide the compound of formula **21**; or

(c"') when X is benzyloxy, converting the vicinal diol of formula **73** to the methylene compound of formula

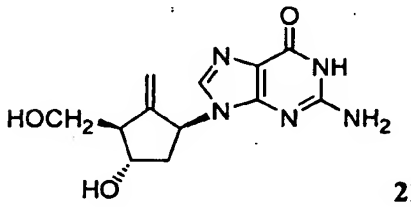


71; and

(d"') converting the silane moiety of compound **71** to a hydroxy moiety to provide the compound of formula **21**.

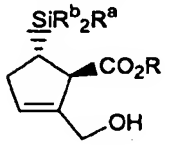
2. The process of Claim 1, in which, in steps (b) and (a"), the diastereoselective epoxidation is performed with a peracid or with a homochiral diester of tartaric acid, a hydroperoxide, and a metal catalyst.

3. A process for the preparation of entecavir having the formula



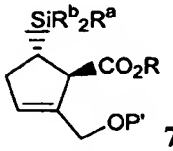
21, comprising:

(a) protecting the hydroxy moiety of an ester of the formula



66,

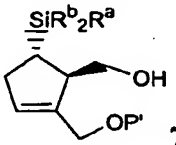
wherein R^a is allyl, phenyl, C_1 to C_6 alkylphenyl, or C_1 to C_6 alkoxyphenyl; R^b is C_1 to C_6 alkyl; and R is C_1 to C_4 alkyl or benzyl, to provide a compound of formula



74',

wherein P' is a protecting group;

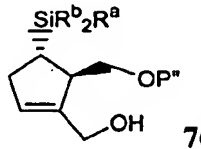
(b) reducing the carboxylic ester moiety of the compound **74'** with at least one reducing reagent to provide a compound of formula,



75';

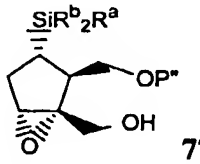
(c) protecting the unprotected hydroxy moiety of compound **75'**, with a protecting group P" that is resistant to conditions used to remove P', then removing

the protecting group P' of the compound of **75'**, to provide the compound having the formula,



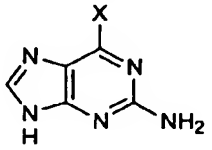
76';

(d) epoxidizing the product from step (c) with a diastereoselective epoxidation to give a cyclopentane epoxide having the formula



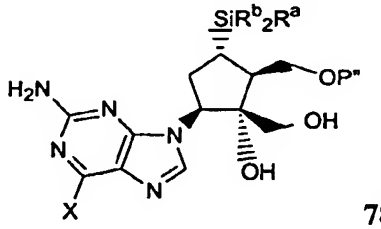
77';

(e) treating the cyclopentane epoxide from step (d) with an alkali metal salt of a purine compound of formula



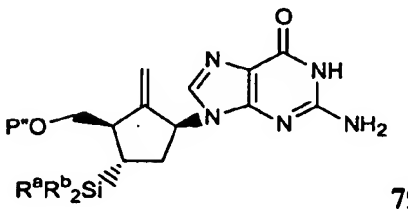
28,

wherein X is Cl, I, or benzyloxy; to give a compound of formula



78'; then

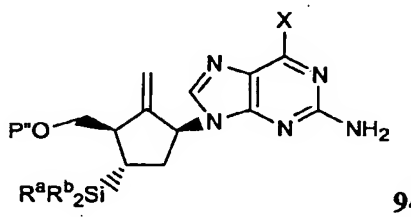
(f) when X is benzyloxy, converting the vicinal diol of formula **78'** to provide the methylene compound of formula



79'; and

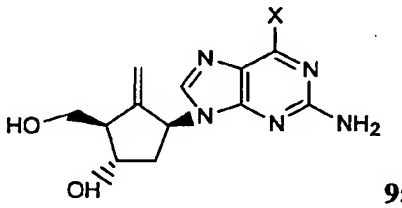
(g) removing the protecting group P" on the primary alcohol of compound **79** and converting the silane moiety to a hydroxy moiety to provide the compound of formula **21**; or

(f') when X is Cl or I, converting the vicinal diol of formula **78'** to provide the methylene compound of formula,



94';

(g') removing the protecting group P" on the primary alcohol of compound **94'** and converting the silane moiety to a hydroxy group to give a compound of formula,



95; and

(h') hydrolyzing the chloro or iodo moiety X to provide the compound of formula **21**.

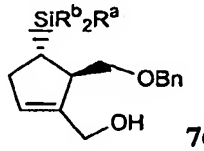
4. The process of Claim 3, wherein, in step (g), the protecting group P" on the primary alcohol of compound **79'** is benzyl, said step of converting the silane moiety of compound **79** to a hydroxy group is achieved with protodesilylation and oxidation, and said benzyl protecting group is removed upon protodesilylation.

5. The process of Claim 3, wherein the protecting group P" on the primary alcohol of compound **79'** is removed after the silane moiety is converted to a hydroxy moiety.

6. The process of Claim 3, wherein in step (a), the hydroxy moiety is protected as a MOP by treatment with 2-methoxypropene and a catalytic amount of a weak acid.

7. The process of Claim 3, wherein in step (b), the carboxylic ester moiety of the compound **74'** is reduced with a hydride reagent selected from at least one of sodium bis(2-methoxyethoxy)aluminum hydride and lithium aluminum hydride in the presence of a base.

8. The process of Claim 3, wherein in step (c), the unprotected hydroxy moiety is protected as a benzyl ether upon treatment with a base and a benzyl halide, wherein, removal of the protecting group P' of the compound of **75'** provides the allylic alcohol having the formula,



76.

9. The process of Claim 8, wherein the base is selected from at least one of potassium *tert*-butoxide, sodium hydride, KHMDS, and aqueous NaOH, and the benzyl halide is benzyl bromide or benzyl chloride.

10. The process of Claim 3, in which in step (d), the diastereoselective epoxidiation is performed by treatment with a peracid.

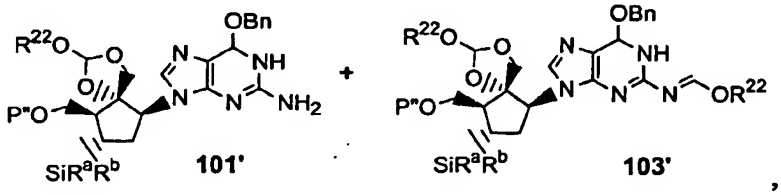
11. The process of Claim 3, in which in step (d), the diastereoselective epoxidiation is performed by treatment with a homochiral diester of tartaric acid, a hydroperoxide, and a metal catalyst

12. The process of Claim 11, wherein the homochiral diester of tartaric acid is (-)-diisopropyl tartrate, the hydroperoxide is *tert*-butylhydroperoxide or α,α-dimethylbenzylhydroperoxide, and the metal catalyst is titanium (IV) isopropoxide.

13. The process of Claim 3, wherein in step (e), the cyclopentane epoxide from step (d) is treated with 2-amino-6-benzyloxypurine in dichloromethane.

14. The process of Claim 3, wherein X is benzyloxy and in step (f), the compound **78'** is converted to the methylene compound of formula **79'** by

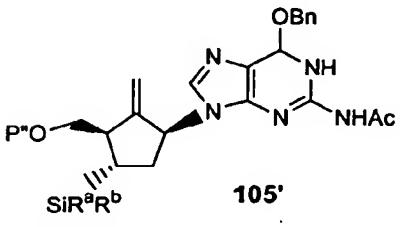
(f)(i) treating compound **78'** with an orthoformate derivative in an inert solvent to produce a diastereomixture of dioxolanes having the formulae **101'** and **103'**,



,

wherein R^{22} is C_{1-4}alkyl or $-C(=O)C_{1-4}$alkyl;

(f)(ii) treating the product from step (f)(i) with an acetic anhydride in the presence of at least one antioxidant to produce an alkene compound having the formula **105'**;



; and

(f) (iii) treating the product from step (f)(ii) with an acid to hydrolyze the 6-benzyloxy and N-acetyl groups to provide the compound of formula **79'**.

15. The process of Claim 14, wherein in step (f)(i), the orthoformate derivative is selected from at least one of diethoxymethyl acetate, diisopropyloxymethyl acetate, TMOF, TEOF, and TiPOF.

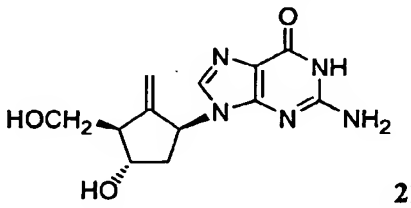
16.The process of Claim 14, wherein in step (f)(ii), at least one antioxidant is selected from BHT and benzoic acid.

17. The process of Claim 3, in which the step of converting the compound **79'** to compound **21** is achieved with protodesilyation and oxidation, wherein the protodesilylation is performed with KOH or NaOH in solvent, or with TFA, and the primary alcohol moiety is deprotected after the silane moiety is converted to a hydroxy group, to provide the compound of formula **21**.

18. The process of Claim 3, in which the step of converting the compound **79'** to compound **21** is achieved with protodesilyation and oxidation, wherein the step of protodesilyation is achieved with at least one acid selected from boron trifluoride-acetic acid complex and a Bronsted acid.

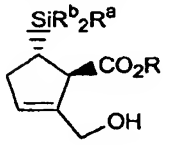
19. The process of Claim 3, in which the step of converting the compound **79'** to compound **21** is achieved with protodesilyation and oxidation, and the oxidation is achieved with hydrogen peroxide in the presence of potassium bicarbonate and optionally potassium fluoride.

20. A process for the preparation of entecavir having the formula



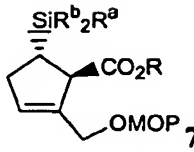
21, comprising:

(a) treating an ester of the formula



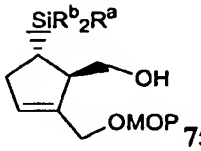
66,

wherein R^a is allyl, phenyl, C_1 to C_6 alkylphenyl, or C_1 to C_6 alkoxyphenyl; R^b is C_1 to C_6 alkyl; and R is C_1 to C_4 alkyl or benzyl; with 2-methoxypropene and a catalytic amount of a weak acid to provide a compound of formula



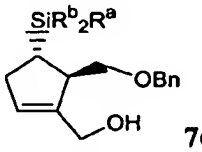
74;

(b) reducing the carboxylic ester moiety of the compound **74** with a hydride reagent selected from at least one of sodium bis(2-methoxyethoxy)aluminum hydride and lithium aluminum hydride, in the presence of a base to provide a compound of formula,



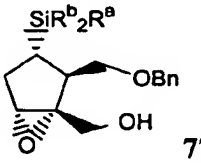
75;

(c) protecting the unprotected hydroxy moiety of compound **75**, as a benzyl ether upon treatment of compound **75** with a base and a benzyl halide, then removing the MOP group of the compound **75**, to provide the allylic alcohol having the formula,



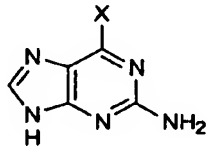
76,

(d) epoxidizing the product from step (c) with (-)-diisopropyl tartrate, *tert*-butylhydroperoxide or cumene hydroperoxide, and titanium (IV) isopropoxide, to give a cyclopentane epoxide having the formula



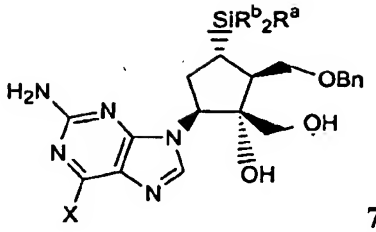
77;

(e) treating the cyclopentane epoxide from step (d) with an alkali metal salt of a purine compound of formula



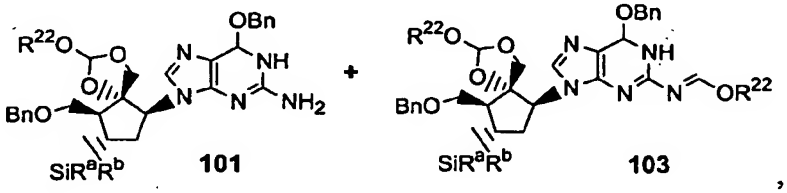
28,

wherein X is benzyloxy; to give a compound of formula



78;

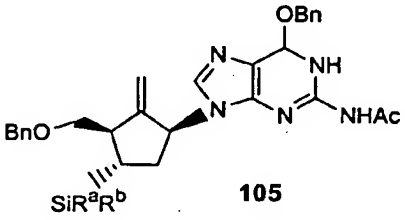
(f))(i) treating compound **78** with an orthoformate derivative selected from diethoxymethyl acetate and diisopropyloxymethyl acetate in an inert solvent to produce a diastereomixture of dioxolanes having the formulae **101** and **103**,



101 **103**

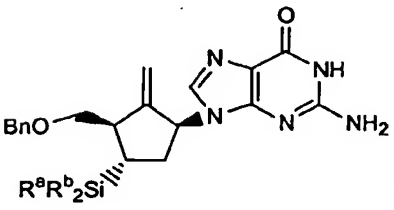
wherein R^{22} is ethyl, –C(=O)ethyl, isopropyl, or –C(=O)isopropyl;

(f)(ii) treating the product from step (f)(i) with an acetic anhydride in the presence of BHT to produce an alkene compound having the formula **105**;



105 ; and

(f) (iii) treating the product from step (f)(ii) with an acid to hydrolyze the 6-benzyloxy and N-acetyl groups and provide the compound of formula **79**,

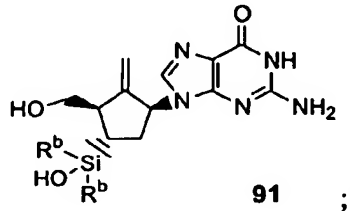


79;

(g) converting the silane moeity to a hydroxy moiety by protodesilylating the silane moiety of compound **79** upon treatment with at least one reagent effective to

achieve protodesilylation, followed by oxidation with a peroxide, and debenzylating compound **79** ,wherein debenzylation may be achieved upon protodesilylation, to provide the compound of formula **21**.

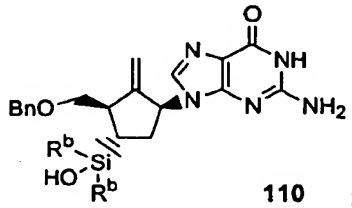
21. The process of Claim 20, in which step (g) comprises treating compound **79** with an acid selected from boron trifluoride-acetic acid complex and a Bronsted acid, wherein said step of protodesilylation removes the benzyl protecting group of compound **79** to provide the compound of formula **91**,



91 ; and

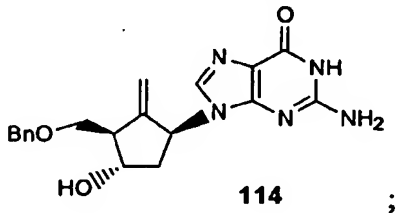
oxidizing the compound **91** with hydrogen peroxide in the presence of potassium bicarbonate and potassium fluoride to provide the compound **21**.

22. The process of Claim 20, in which step (g) comprises treating compound **79** with potassium hydroxide or sodium hydroxide in solvent, or TFA to provide the compound of formula **110**,



110 ;

oxidizing compound **110** with hydrogen peroxide in the presence of potassium bicarbonate and potassium fluoride to provide the compound **114**;



114 ;

and debenzylating compound **114** to provide compound **21**.

23. A method for isolating entecavir or an entecavir intermediate from a diluted mixture, the diluted mixture comprising entecavir and water or a mixture comprising an entecavir intermediate and other process reagents comprising:

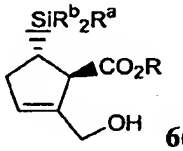
(a) adsorbing the diluted mixture onto a hydrophobic resin bed;

(b) washing the resin bed with water to remove salt; and

(c) eluting the entecavir or entecavir intermediate from the resin bed with an organic solvent.

24. The method of Claim 23 wherein the hydrophobic resin is a brominated styrene based resin.

25. A process for the preparation of an ester of the formula



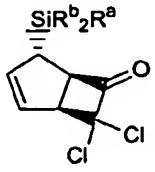
66,

wherein R^a is alkyl, phenyl, C_1 to C_6 alkylphenyl, or C_1 to C_6 alkoxyphenyl; R^b is C_1 to C_6 alkyl; and R is C_1 to C_4 alkyl or benzyl comprising:

(a) reacting a cyclopentadienide ion

with a silylating reagent having the formula $R^a(R^b)_2Si$-Y, wherein Y is a leaving group; and

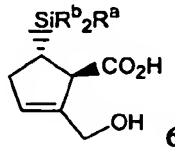
(b) reacting the product of step (a) with a ketene to give a cyclobutanone of the formula



63;

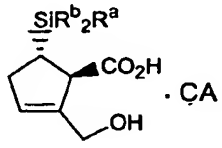
(c) treating the product from step (b) with a base effective for opening the cyclobutanone ring;

(d) reducing the product from step (c) with a reducing agent to give a racemic carboxylic acid of the formula



64;

(e) resolving the product from step (d) by treatment with a chiral amine and separation of the resulting diastereomeric salts to give a compound of formula



65A

wherein CA represents a chiral amine; and

(f) heating the product from step (e) in a solution of an acidic solution to give the ester product of formula **66**.

26. The process of Claim 25, in which, in step (b), the ketene is formed from dichloroacetyl chloride and a base.

27. The process of Claim 25, in which, in step (c), the base is potassium carbonate in *t*-butanol.

28. The process of Claim 25, in which, in step (d), the reducing reagent is $NaBH_4$.

29. The process of Claim 25, in which, in step (e), the chiral amine is selected from the group consisting of R,R-(-)-2-amino-1-(4-nitrophenyl)-1,3-propanediol, (1R,2R)-(+)-1,2-diphenylethylenediamine, (R)-(-)-1-cyclohexylethylamine, D-threo-2-amino-1-(4-nitrophenyl)-1,3-propanediol, (1S,2S)-(+)1, 2-diaminocyclohexane, dehydroabietylamine, (1R,2R)-1,2-diaminomethylcyclohexane, cichonidine, and cinchonine.

30. The process of Claim 25, in which, in step (f), the acidic solution comprises a solution of an alcohol, R-OH, wherein R is C_1 to C_4 alkyl or benzyl, and an acid.

31. The process of Claim 25, in which,

in step (b), the ketene is formed from dichloroacetyl chloride and a base;

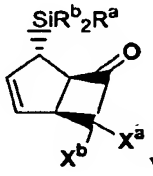
in step (c), the base is potassium carbonate in *t*-butanol;

in step (d), the reducing reagent is $NaBH_4$;

in step (e), the chiral amine is R,R-(-)-2-amino-1-(4-nitrophenyl)-1,3-propanediol; and

in step (f), the acidic solution comprises a solution of an alcohol, R-OH, wherein R is C_1 to C_4 alkyl or benzyl, and an acid.

32. A compound of formula



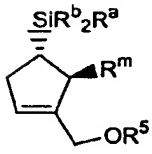
wherein:

R^a is allyl, phenyl, C_1 to C_6 alkylphenyl or C_1 to C_6 alkoxyphenyl;

R^b is C_1 to C_6 alkyl; and

X^a and X^b are halide.

33. A compound of formula



or a salt thereof wherein:

R^a is allyl, phenyl, C_1 to C_6 alkylphenyl or C_1 to C_6 alkoxyphenyl;

R^b is C_1 to C_6 alkyl;

R^m is $-CO_2R^6$ or $-CH_2OR^6$;

R^5 is hydrogen or a hydroxy protecting group; and

R^6 is hydrogen, C_1 to C_4 alkyl, or benzyl.

34. A compound of Claim 33 wherein:
R^m is $-CO_2R^6$; and
R^5 and R^6 are both hydrogen.

35. The compound of Claim 34 wherein:
R^a is phenyl; and
R^b is methyl.

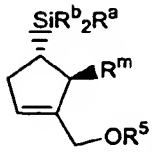
36. A compound of Claim 33 as a salt with a chiral amine selected from the group consisting of R,R-(-)-2-amino-1-(4-nitrophenyl)-1,3-propanediol, (1R,2R)-(+)-1,2-diphenylethylenediamine, (R)-(-)-1-cyclohexylethylamine; D-threo-2-amino-1-(4-nitrophenyl)-1,3-propanediol, (1S,2S)-(+)-1, 2-diaminocyclohexane, dehydroabietylamine, (1R,2R)-1 , 2-diaminomethylcyclohexane, cinchonidine, and cinchonine.

37. The compound of Claim 36 wherein:
R^m is $-CO_2R^6$;
R^5 and R^6 are both hydrogen;
R^a is phenyl;
R^b is methyl; and
the chiral amine is R,R-(-)-2-amino-1-(4-nitrophenyl)-1,3-propanediol.

38. The compound of Claim 33 wherein:
R^m is $-CH_2OR^6$;
R^5 is hydrogen; and
R^6 is benzyl.

39. The compound of Claim 38 wherein:
R^a is phenyl; and
R^b is methyl.

40. A compound having the formula



or a salt thereof wherein:

R^a is phenyl;

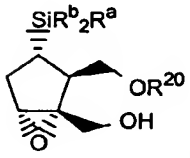
R^b is C_1 to C_6 alkyl;

R^m is $-CO_2R^6$ or $-CH_2OR^6$;

R^5 is hydrogen or a hydroxy protecting group; and

R^6 is hydrogen, C_1 to C_4 alkyl, or benzyl, said compound produced according to the process of claim 22.

41. A compound of formula



wherein:

R^a is alkyl, phenyl, C_1 to C_6 alkylphenyl, or C_1 to C_6 alkoxyphenyl;

R^b is C_1 to C_6 alkyl; and

R^{20} is hydrogen or benzyl.

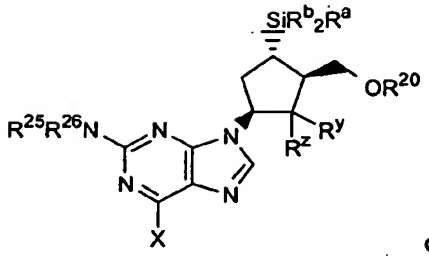
42. The compound of Claim 41 wherein:

R^a is phenyl;

R^b is methyl; and

R^{20} is benzyl.

43. A compound of formula



or a salt thereof wherein:

R^a is alkyl, phenyl, C_1 to C_6 alkylphenyl, or C_1 to C_6 alkoxyphenyl;

R^b is C_1 to C_6 alkyl;

R^{20} is hydrogen or benzyl;

X is Cl, I, or benzyloxy;

R^y and R^z are taken together to form methylene (=CH_2), or R^y is OR^{23}, and R^z is -CH_2OR^{24}, wherein R^{23} and R^{24} are each hydrogen or are taken together to form a ring to define a dioxolane, said dioxolane being optionally substituted with -O(C_{1-4}alkyl) or –O(C=O)(C_{1-4}alkyl); and

R^{25} and R^{26} are both hydrogen, or one of R^{25} and R^{26} is hydrogen and the other is acyl; or R^{25} and R^{26} are taken together to form =CH(OC_{1-4}alkyl) or =CH(OC(=O)C_{1-4}alkyl).

44. The compound of Claim 43 wherein:

R^a is phenyl;

R^b is methyl; and

X is benzyloxy.

45. The compound of claim 44 in which

R^{20} is benzyl;

R^y is OH, and R^z is -CH_2OH, and

R^{25} and R^{26} are both hydrogen.

46. The compound of Claim 43 wherein:

R^a is phenyl;

R^b is methyl;

X is benzyloxy;

R^y is OR^{23}, and R^z is $-CH_2OR^{24}$, wherein R^{23} and R^{24} combine to form a dioxolane optionally substituted with $-O(C_{1-4}alkyl)$ or $O(C=O)(C_{1-4}alkyl)$; and

R^{25} and R^{26} are both hydrogen, or R^{25} and R^{26} are taken together to form $=CH(OC_{1-4}alkyl)$ or $=CH(O(C=O)C_{1-4}alkyl)$.

47. The compound of Claim 43 wherein:

R^a is phenyl;

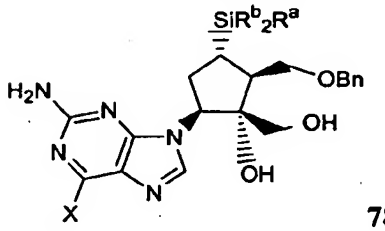
R^b is methyl;

X is benzyloxy;

R^y and R^z are taken together to form methylene; and

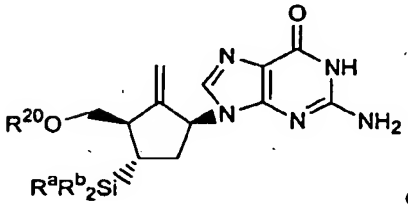
R^{25} is hydrogen and R^{26} is acyl.

48. The compound of Claim 43 having the formula,



78.

49. A compound of formula



or a salt thereof, wherein:

R^a is alkyl, phenyl, C_1 to C_6 alkylphenyl, or C_1 to C_6 alkoxyphenyl;

R^b is C_1 to C_6 alkyl; and

R^{20} is hydrogen or benzyl.

50. The compound of Claim 49 wherein:

R^a is phenyl;

R^b is methyl; and

R^{20} is hydrogen.

51. The compound of Claim 49 wherein:

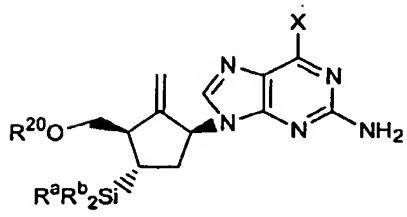
R^a is phenyl;

R^b is methyl; and

R^{20} is benzyl.

52. The methanesulfonate salt of the compound of Claim 51.

53. A compound of formula



or a salt thereof, wherein:

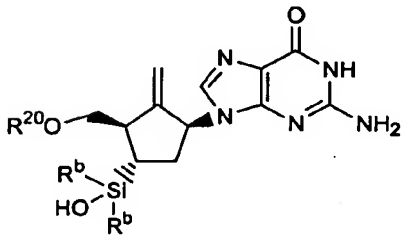
X is Cl or I;

R^a is alkyl, phenyl, C_1 to C_6 alkylphenyl, or C_1 to C_6 alkoxyphenyl;

R^b is C_1 to C_6 alkyl; and

R^{20} is hydrogen or benzyl.

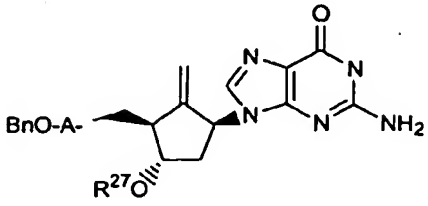
54. A compound of formula



wherein R^b is C_1 to C_6 alkyl; and R^{20} is hydrogen or benzyl, or a salt thereof.

55. The compound of Claim 54 wherein R^b is methyl.

56. A compound of formula



or a salt thereof, wherein:

A is CH_2 or a bond;

R^{27} is hydrogen, benzyl, or $SiR^d_2R^c$;

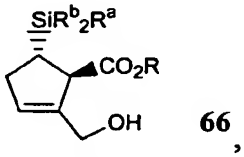
R^c is C_1 to C_4 alkyl or phenyl; and

R^d is C_1 to C_3 alkyl.

57. A compound of claim 56, in which A is a bond, and R^{27} is hydrogen.

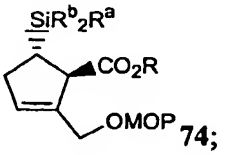
58. A method for making a compound of formula **78**, according to Claim 48, comprising,

(a) treating an ester of the formula



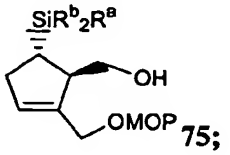
66,

wherein R^a is allyl, phenyl, C_1 to C_6 alkylphenyl, or C_1 to C_6 alkoxyphenyl; R^b is C_1 to C_6 alkyl; and R is C_1 to C_4 alkyl or benzyl; with 2-methoxypropene and a catalytic amount of a weak acid to provide a compound of formula



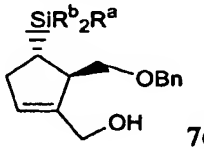
74;

(b) reducing the carboxylic ester moiety of the compound **74** with at least one hydride reagent to provide a compound of formula,



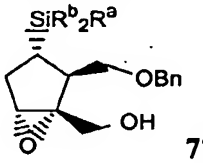
75;

(c) protecting the unprotected hydroxy moiety of compound **75**, as a benzyl ether upon treatment of compound **75** with a base and a benzyl halide, then removing the MOP group of the compound **75**, to provide the allylic alcohol having the formula,



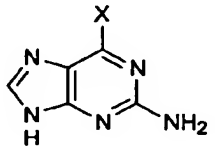
76,

(d) epoxidizing the product from step (c) with a diastereoselective expoxidation, to give a cyclopentane epoxide having the formula



77;

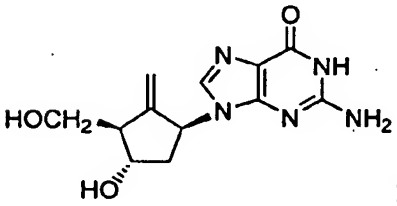
(e) treating the cyclopentane epoxide from step (d) with an alkali metal salt of a purine compound of formula



28,

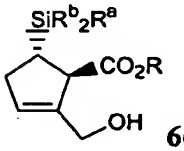
wherein X is benzyloxy; I, or Cl, to give a compound of formula **78.**

59. A process for the preparation of entecavir having the formula



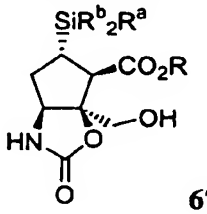
21, comprising:

(a) converting an ester having the formula



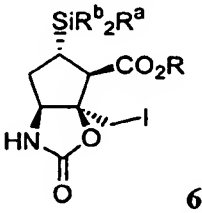
66

wherein R is C_1 to C_4 alkyl, or benzyl; R^a is allyl, phenyl, C_1 to C_6 alkylphenyl or C_1 to C_6 alkoxyphenyl, and R^b is C_1 to C_6 alkyl, under aminohydroxylation conditions to give an oxazolidinone having the formula



67;

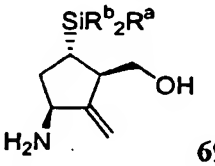
(b) converting the alcohol of the oxazolidinone of formula **67** with an iodide salt to give an iodide having the formula



68;

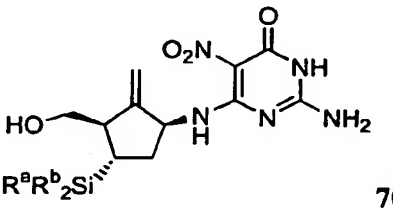
(c) treating the iodide of formula **68** with zinc and acetic acid;

(d) treating the product of step (c) with a hydride reagent to reduce the ester moiety to an alcohol and give a methylene compound of formula



69 or a salt thereof;

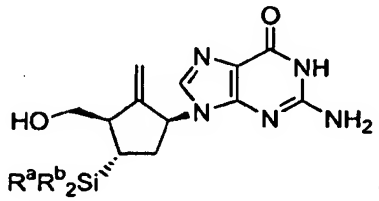
(e) reacting the methylene compound of formula **69** with 6-chloro-2-amino-5-nitro-4(3H)-pyrimidinone in the presence of base to give a pyrimidine compound having the formula



70;

(f) treating the pyrimidine compound of formula **70** with a reducing agent to reduce the nitro moiety to an amine;

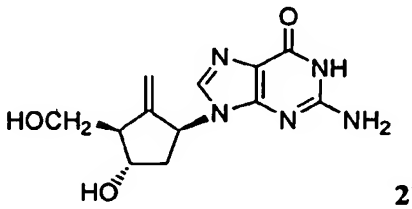
(g) cyclizing the product of step (f) with an orthoformate derivative and an acid to give a methylene compound having the formula



71; and

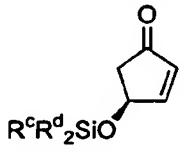
(h) converting the silane moiety of the compound of formula **71** to a hydroxy moiety and providing the compound of formula **21**.

60. A process for the preparation of entecavir having the formula



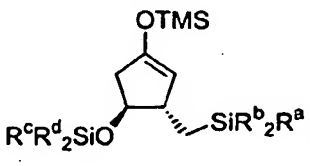
21, comprising:

(a) treating 4-(S)-hydroxy-2-cyclopenten-1-one with a silylating reagent of the formula $R^cR^d{}_2SiY$ and a trialkylamine base wherein R^c is C_1 to C_4 alkyl or phenyl, R^d is C_1 to C_3 alkyl, and Y is a leaving group to give the compound of formula



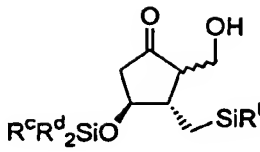
33;

(b) treating the product from step (a) with a Grignard reagent prepared from a (halomethyl)silane reagent of the formula $R^aR^b{}_2SiCH_2X'$, wherein R^a is allyl, phenyl, C_1 to C_6 alkylphenyl or C_1 to C_6 alkoxyphenyl; R^b is C_1 to C_6 alkyl; and X′ is chloro, bromo, or iodo followed by treatment with trimethylsilylating reagent to give a compound of formula



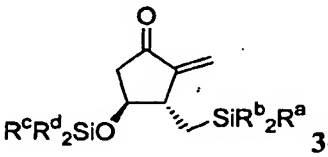
34;

(c) formylating the compound of formula **34** to give a compound of formula

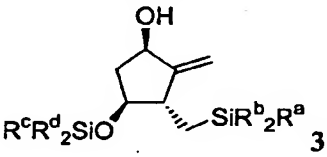

35;

(d) treating the compound of formula **35** with a sulfonylating reagent having the formula R^3SO_2Cl, wherein R^3 is C_1 to C_4 alkyl, trifluoromethyl, phenyl or phenyl substituted by C_1 to C_6 alkyl or C_1 to C_6 alkoxy;

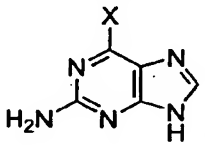
(e) reacting the product of step (d) with a strong base to eliminate a sulfonate group to provide a methylene compound of formula

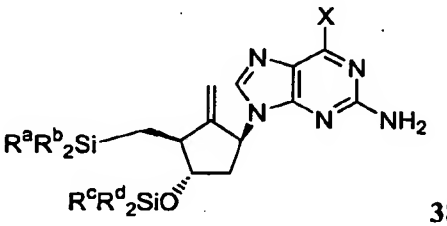

36;

(f) selectively reducing the methylene compound of formula **36** with a hydride reagent to provide an allylic alcohol of the formula


37;

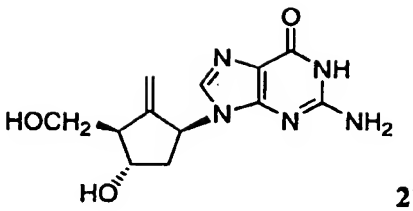
(g) condensing the allylic alcohol of the formula **37** under Mitsonobu conditions with a purine compound of formula


28, wherein X is Cl, I, or benzyloxy, to provide a methylene compound of formula


38; and

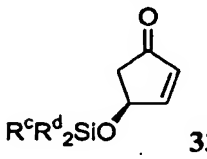
(h) converting the compound of formula **38** to the compound of formula **21**.

61. A process for the preparation of entecavir having the formula



21, comprising:

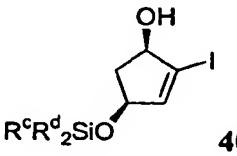
(a) reacting a cyclopentenone of the formula



33

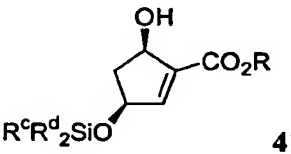
with iodine, wherein R^c is C_1 to C_4 alkyl, or phenyl, and R^d is C_1 to C_3 alkyl;

(b) reducing the carbonyl group of the product of step (a) to provide an iodo compound of formula



40;

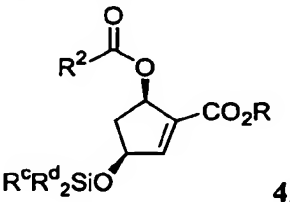
(c) converting the iodo compound of formula 40 to give a compound of formula



41,

wherein R is C_1 to C_4 alkyl, or benzyl;

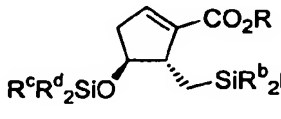
(d) acylating the compound of formula **41** with an activated acyl agent of the formula $R^2C(O)$-Y wherein R^2 is C_1 to C_6 alkyl, arylalkyl or aryl, and Y is a leaving group to give a compound of formula



42;

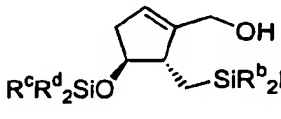
(e) treating the product of step (d) with a Grignard reagent prepared from a (halomethyl)silane reagent of the formula $R^aR^b{}_2SiCH_2X'$, wherein R^a is allyl, phenyl,

C_1 to C_6 alkylphenyl or C_1 to C_6 alkoxyphenyl; R^b is C_1 to C_6 alkyl; and X′ is chloro, bromo, or iodo to give an ester of the formula



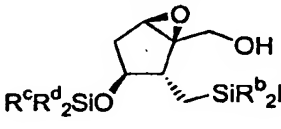
43;

(f) reducing the ester of formula **43** with a hydride reagent to provide an allylic alcohol of the formula



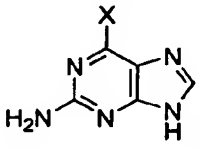
44;

(g) epoxidizing the allylic alcohol of formula **44** with an oxidizing agent to provide a cyclopentane epoxide of the formula



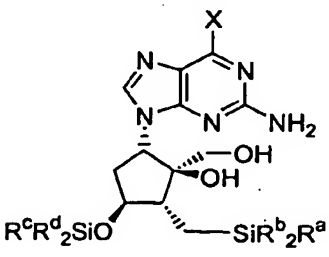
45;

(h) reacting the cyclopentane epoxide of formula **45** with an alkali metal salt of a purine compound of formula



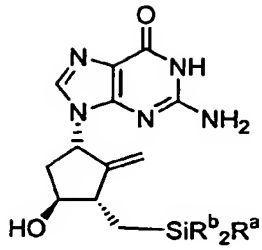
28

wherein X is Cl, I or benzyloxy, to give a compound of formula



46;

(i) converting the compound of formula **46** to a methylene compound of formula

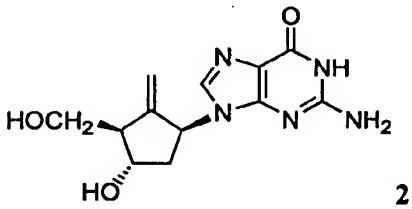


47;

(j) treating the compound of formula **47** with an acid or base effective for protodesilylation of the silyl moiety; and

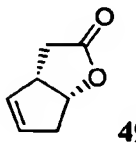
(k) oxidizing the product of step (j) to provide the compound of formula **21**.

62. A process for the preparation of entecavir having the formula



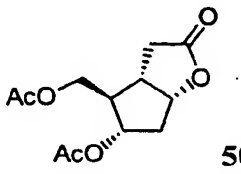
21, comprising:

(a) treating a homochiral bicyclic lactone of the formula



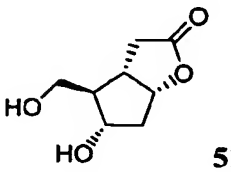
49

with paraformaldehyde, acetic acid, and sulfuric acid to provide a diacetate of the formula



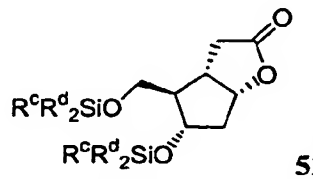
50;

(b) treating the diacetate product of step (a) using a base in an alcohol solvent to remove the acetate protecting groups to give the compound having the formula



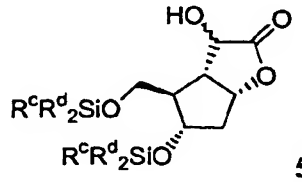
51;

(c) treating the product of step (b) with a silylating reagent of the formula $R^cR^d{}_2SiY$, wherein R^c is linear or branched C_1 to C_4 alkyl, or phenyl, and R^d is linear or branched C_1 to C_3 alkyl and Y is a leaving group, to provide a compound of formula



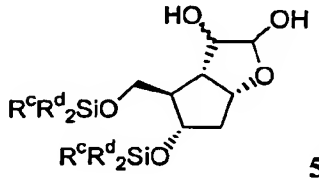
52;

(d) treating the product of step (c) with a strong non-nucleophilic base and (1S)-(+)-(10-camphorsulfonyl)oxaziridine to give a compound of formula



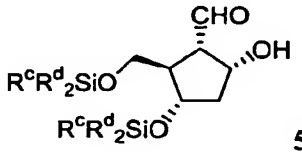
53;

(e) reducing the lactone moiety of the product from step (d) with a hydride reagent to give a compound having the formula



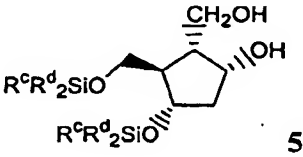
53A;

(f) cleaving the product from step (e) with an oxidizing agent to give a compound of formula



53B;

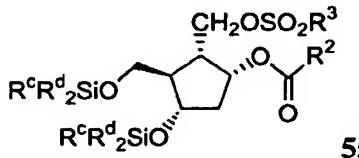
(g) reducing the product from step (f) with a hydride reagent to give a diol of the formula



54;

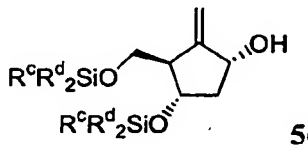
(h) selectively sulfonylating the primary alcohol of the product from step (g) with a reagent of the formula R^3SO_2Cl, wherein R^3 is C_1 to C_4 alkyl, trifluoromethyl, phenyl, or phenyl substituted by C_1 to C_6 alkyl or C_1 to C_6 alkoxy;

(i) acylating the secondary alcohol of the product of step (h) with an acylating agent of the formula $R^2C(O)$-Y, wherein R^2 is C_1 to C_6 alkyl, arylalkyl or aryl, and Y is a leaving group to give a compound having the formula



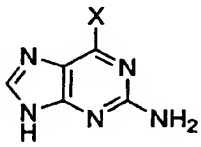
55;

(j) treating the product from step (i) with a strong base to effect elimination and hydrolysis of the carboxylic acid ester to give the compound of formula



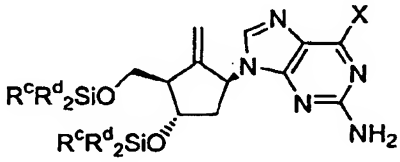
56;

(k) condensing the product from step (j) with a purine compound of formula



28

wherein X is Cl, I or benzyloxy, under Mitsonobu conditions to give a methylene compound of formula

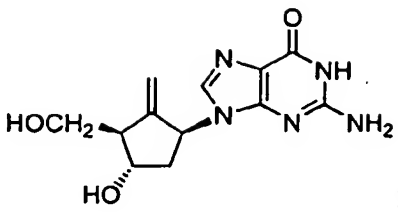


57;

(l) removing the silyl ether protecting groups of the methylene compound of formula **57**; and

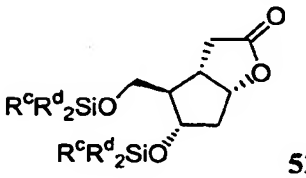
(m) hydrolyzing the 6-X group to give the compound of formula **21**.

63. A process for the preparation of entecavir having the formula



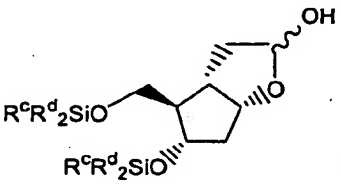
21, comprising:

(a) reducing the compound of formula



52

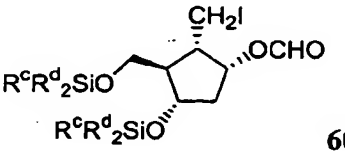
to give a lactol of the formula



59

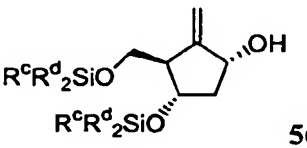
wherein R^c is a linear or branched C_1 to C_4 alkyl, or phenyl, and R^d is a linear or branched C_1 to C_3 alkyl;

(b) iodinating the lactol product of step (a) by free radical oxidation to give an iodide compound having the formula



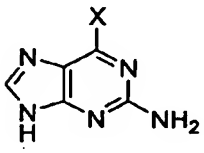
60;

(c) treating the product from step (b) with a strong base to give the methylene compound of formula



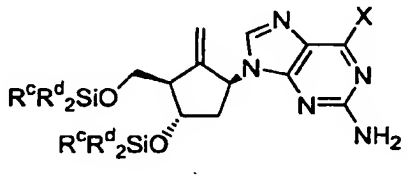
56;

(d) condensing the product from step (c) with a purine compound of formula



28

wherein X is Cl, I or benzyloxy, under Mitsonobu conditions to give a methylene compound of formula

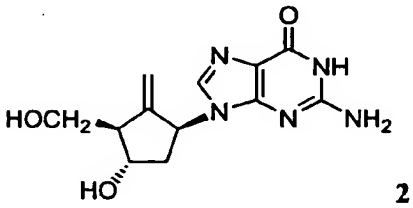


57;

(e) removing the silyl ether protecting groups of the methylene compound of formula **57**; and

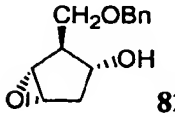
(f) hydrolyzing the 6-X group to give the compound of formula **21**.

64. A process for the preparation of entecavir having the formula



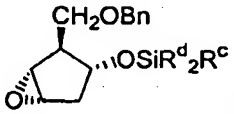
21, comprising:

(a) silylating a compound of formula



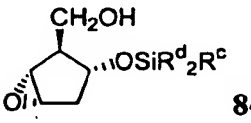
82

with a compound of formula $R^cR^d{}_2SiY$, wherein R^c is linear or branched C_1 to C_4 alkyl, or phenyl, R^d is linear or branched C_1 to C_3 alkyl, and Y is a leaving group, to provide a compound of formula



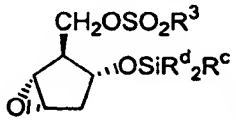
83;

(b) reducing the product from step (a) under conditions sufficient to remove the benzyl protecting group to give a compound of formula



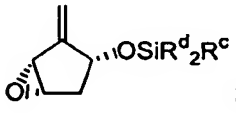
84;

(c) converting the alcohol moiety of the product from step (b) to a sulfonate ester of the formula SO_2R^3, wherein R^3 is C_1 to C_4 alkyl, trifluoromethyl, or phenyl substituted by C_1 to C_6 alkyl or C_1 to C_6 alkoxy to give a compound of formula



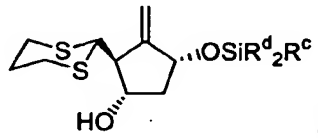
85;

(d) treating the product from step (c) with a strong base to effect elimination of the R^3SO_3H to provide the methylene compound of formula



86;

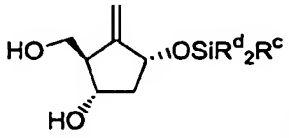
(e) treating the product from step (d) with a lithium salt of 1,3-dithiane to provide the compound of formula



87;

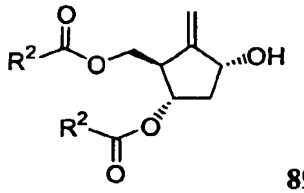
(f) hydrolyzing the dithioacetal moiety of the compound of formula **87**; and

(g) treating the product of step (f) with a hydride reagent to provide a compound of formula



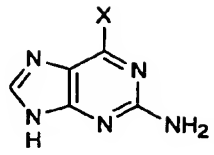
88;

(h) acylating the compound of formula **88** with a compound having the formula $R^2C(O)$-Y, wherein Y is a leaving group and R^2 is C_1 to C_6 alkyl or aryl, to give the compound of formula



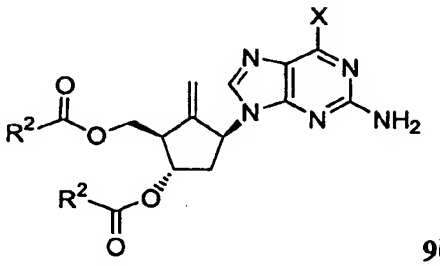
89;

(i) condensing the product from step (h) with a purine compound of formula



28

wherein X is Cl, I, or benzyloxy under Mitsonobu conditions to give a methylene compound of formula

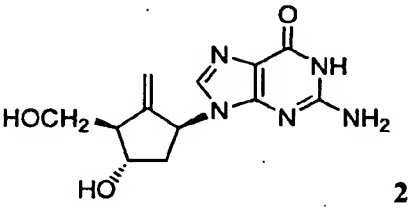


90;

(j) removing the acyl ester protecting groups from the methylene compound of formula **90**; and

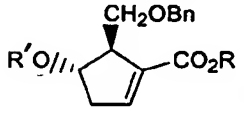
(k) hydrolyzing the X group to give the compound of formula **21.**

65. A process of preparing entecavir having the formula



21, comprising:

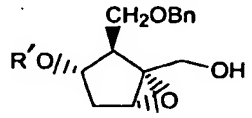
(a) reducing an ester of the formula



7

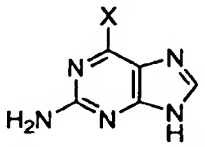
wherein R is C_1 to C_4 alkyl, or benzyl, and R′ is benzyl, benzyl substituted on the phenyl moiety by C_1 to C_6 alkyl or C_1 to C_6 alkoxy, or $R^cR^d{}_2Si$ wherein R^c is linear or branched C_1 to C_4 alkyl or phenyl, and R^d is linear or branched C_1 to C_3 alkyl, with a hydride reagent;

(b) asymmetrically epoxidizing the product from step (a) with a homochiral diester of tartaric acid, a hydroperoxide, and a metal catalyst to provide the cyclopentane epoxide of the formula



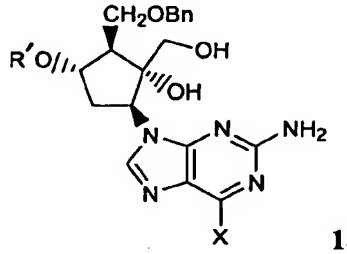
17;

(c) treating the product of step (b) with an alkali metal salt of a purine compound of formula



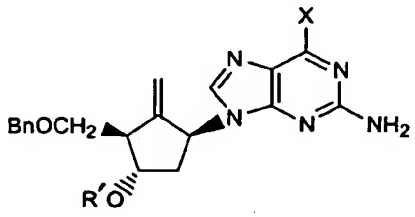
28

wherein X is Cl, I or BnO, to provide a compound of formula



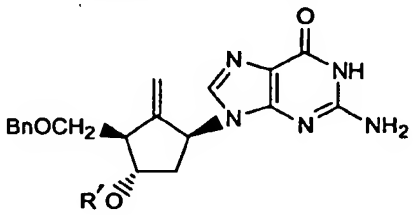
18;

(d) converting the vicinal diol product of step (c) to an alkene to provide the methylene compound of formula



19;

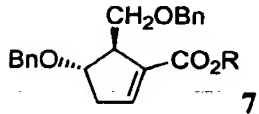
(e) hydrolyzing the X group of the compound of formula **19** to provide the methylene compound of formula



20; and

(f) removing the benzyl ether protecting group(s) to provide the compound of formula **21**.

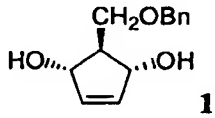
66. A process for the preparation of an ester of the formula



7

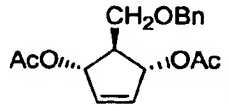
wherein R is C_1 to C_4 alkyl or benzyl, comprising:

(a) acetylating a diol of the formula



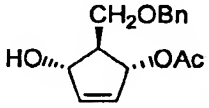
1

with an anhydride to provide the diacetate of the formula



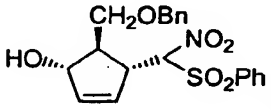
2;

(b) hydrolyzing the product from step (c) with a hydrolase enzyme to give a compound of formula



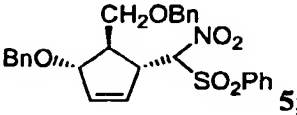
3;

(c) coupling the product from step (b) with phenylsulfonylnitromethane to give a compound of formula



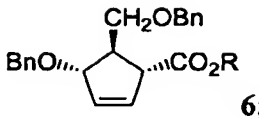
4;

(d) alkylating the product from step (c) with a benzyl halide to provide the compound of formula



5;

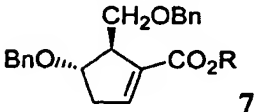
(e) converting the product from step (d) to an ester of the formula



6; and

(f) isomerizing the ester of the formula **6** under basic conditions to provide the ester of the formula **7**.

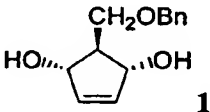
67. A process for the preparation of an ester of the formula



7

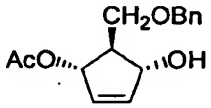
wherein R is C_1 to C_4 alkyl or benzyl, comprising:

(a) asymmetrically acetylating the diol of the formula



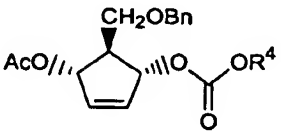
1

with a C_1 to C_6 alkyl acetate ester and hydrolase enzyme to obtain a compound of formula



13;

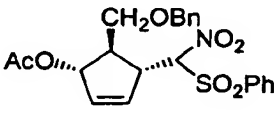
(b) acylating the product from step (a) to give an alkyl carbonate of the formula



14

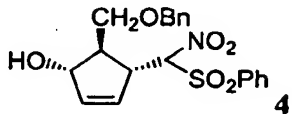
wherein R^4 is C_1 to C_6 alkyl, benzyl, phenyl, or phenyl substituted by C_1 to C_6 alkyl or C_1 to C_6 alkoxy;

(c) coupling the product from step (b) with phenylsulfonylnitromethane to obtain a compound of formula



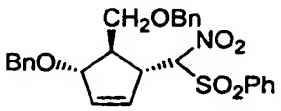
15;

(d) hydrolyzing the product from step (c) with a base to obtain a compound of formula



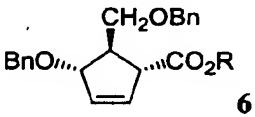
4;

(e) alkylating the product from step (d) with a benzyl halide in the presence of strong non-nucleophilic base to give the compound of formula



5;

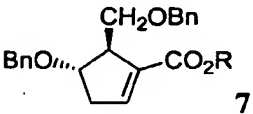
(f) converting the product from step (e) to an ester of the formula



6 ; and

(g) isomerizing the ester of the formula **6** under basic conditions to provide the ester of the formula **7**.

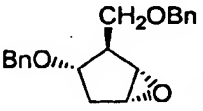
68. A process for the preparation of an ester of the formula



7

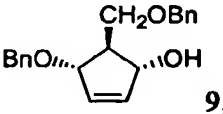
wherein R is C_1 to C_4 alkyl or benzyl, comprising:

(a) reacting a cyclopentane epoxide of the formula



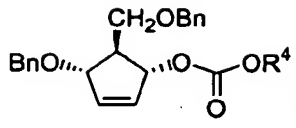
8

with a strong non-nucleophilic base to form an allylic alcohol of the formula



9;

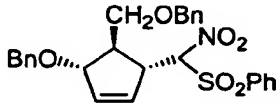
(b) acylating the product from step (a) to give an alkyl carbonate ester of the formula



10

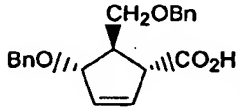
wherein R^4 is C_1 to C_6 alkyl, benzyl, phenyl, or phenyl substituted by C_1 to C_6 alkyl or C_1 to C_6 alkoxy;

(c) coupling the product of step (b) with phenylsulfonylnitromethane to give the compound of formula



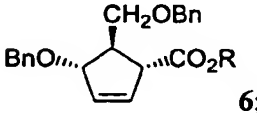
5;

(d) converting the product from step (c) to an acid of the formula



11;

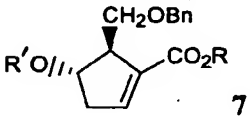
(e) converting the product from step (d) to an ester of the formula



6; and

(f) isomerizing the product from step (e) under basic conditions to provide the ester of formula **7**.

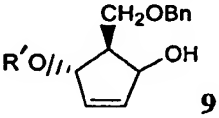
69. A process of preparing an ester of the formula



7

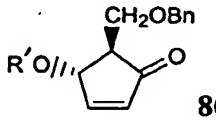
wherein R is C_1 to C_4 alkyl, or benzyl; R′ is benzyl, or benzyl substituted on the phenyl moiety by C_1 to C_6 alkyl or C_1 to C_6 alkoxy, or $R^cR^d{}_2Si$, wherein R^c is C_1 to C_4 alkyl, or phenyl, and R^d is C_1 to C_3 alkyl; comprising:

(a) oxidizing an allylic alcohol of the formula



9

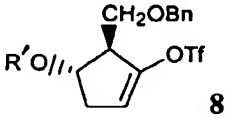
with an oxidizing agent to give a cyclopentenone of the formula



80;

(b) reducing the cyclopentenone of the formula **80** with lithium tri-*sec*-butylborohydride;

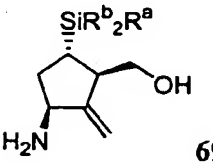
(c) sulfonylating the product of step (b) with a triflating reagent to give a compound of formula



81; and

(d) converting the triflate moiety of the compound of formula **81** to an alkoxycarbonyl moiety to give the ester of the formula **7**.

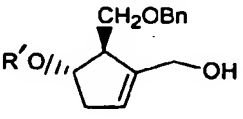
70. A compound of formula



69

wherein R^a is allyl, phenyl, C_1 to C_6 alkylphenyl or C_1 to C_6 alkoxyphenyl; and R^b is C_1 to C_6 alkyl; or a salt thereof.

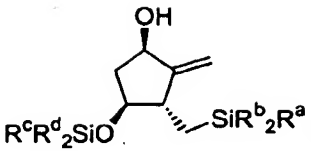
71. A compound of formula



16

or a salt thereof wherein R^1 is benzyl or $R^cR^d{}_2Si$-, R^c is C_1 to C_4 alkyl or phenyl, and R^d is C_1 to C_3 alkyl.

72. A compound of formula



37 or a salt thereof wherein:

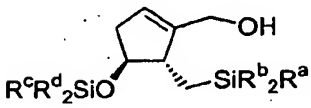
R^a is allyl, phenyl, C_1 to C_6 alkylphenyl or C_1 to C_6 alkoxyphenyl;

R^b is C_1 to C_6 alkyl;

R^c is C_1 to C_4 alkyl or phenyl; and

R^d is C_1 to C_3 alkyl.

73. A compound of formula



44 or a salt thereof wherein:

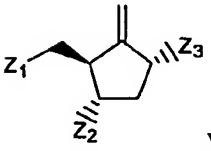
R^a is allyl, phenyl, C_1 to C_6 alkylphenyl or C_1 to C_6 alkoxyphenyl;

R^b is C_1 to C_6 alkyl;

R^c is C_1 to C_4 alkyl or phenyl; and

R^d is C_1 to C_3 alkyl.

74. A compound of formula



wherein Z_1 and Z_2 are both $R^cR^d{}_2SiO$- and Z_3 is hydroxy or Z_1 and Z_2 are both hydroxy and Z_3 is $R^cR^d{}_2SiO$-;

R^c is C_1 to C_4 alkyl or phenyl; and

R^d is C_1 to C_3 alkyl.